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CONSIDERATIONS FOR SELECTING FIELD-BASED STRENGTH AND POWER FITNESS TESTS TO MEASURE ASYMMETRIES

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Abstract

The prevalence of lower limb asymmetries has been reported in numerous studies; however, methodological differences exist in the way they can be detected. Strength and jumping-based tasks have been most commonly used to examine these differences across both athlete and non-athlete populations. The aim of this review was to critically analyze the utility of strength and jumping tests that are frequently used to measure asymmetry. Reliability, validity, and considerations for assessment are examined to enhance test accuracy and effectiveness in the quantification of asymmetries during strength and jumping-based tasks. Medline and SPORT Discus databases were used with specific search terms to identify relevant articles in both athlete and non-athlete populations. The findings of the current review indicate that assessing inter-limb differences during strength and jumping-based tasks may result in different levels of asymmetry; thus, inter-limb differences appear to be task-dependent. Consequently, quantification during both types of assessment is warranted and a selection of tests has been suggested to measure asymmetries in both strength and jumping-based tasks.

Key Words: Asymmetries, Reliability, Strength, Jumping

Introduction

The concept of asymmetries has attracted much interest in strength and conditioning (S&C) in recent years. Multiple studies have reported the prevalence of asymmetries during a variety of jumping (7,23,32,65) and strength-based assessments (4,24,47,56,58); however, a critical analysis of their utility for measuring inter-limb differences and clear guidelines for implementation are sparse. Within the available literature, methodological differences exist with regards to the type of test used and their administration procedures. The countermovement jump (CMJ) and single leg CMJ (SLCMJ) have been most commonly used (7,13,36,43,47,63), most likely due to their ease of application. However, solely measuring lower body jumping-based tasks in a vertical direction will reduce the ecological validity for a range of sports which require movements in multiple planes of motion and a range of physical qualities. Previous data also indicate that measures of strength, such as the back squat (22,47,58), isometric squat or mid-thigh pull (IMTP) (4,25,30,65), and isokinetic knee flexion or extension (15,18,56,59) have shown adequate sensitivity to identify between-limb differences. Furthermore, any highlighted inter-limb differences in strength and jumping tasks have shown decrements in physical performance (4,7,69), increased injury risk (35), and reduced performance in sport-specific tasks (26). Therefore, to provide an accurate profile to screen athletes for the presence of asymmetry, a battery of tests may be required due to the potential for task sensitivity across a range of physical competencies.

When calculating asymmetries, a variety of approaches have been used which define limb differences in terms of dominance, strength, preference, or simply a right or left distinction (10). For example, studies pertaining to soccer frequently define the dominant limb as the favoured ‘kicking leg’ (15, 56), which seems valid considering the nature of such a task. However, recent research has highlighted poor levels of agreement (40%) between perceived limb dominance and the highest score attained (23). In addition, Zifchock et al. (70)

suggested that numerous asymmetry equations emphasise the use of a 'reference value' (such as the dominant limb or highest score); however, clarity is sometimes lacking as to why one limb is chosen over the other. Therefore, precision on defining limb dominance is critical and must retain specificity to the task in question.

A combination of factors exist that should be considered prior to the selection of appropriate tests to measure asymmetry. These include test reliability to ensure there is adequate precision in the outcome measures used to enable practitioners to accurately quantify inter-limb differences. Associations with reductions in performance or heightened injury risk should also be considered in determining the usefulness of a test. Finally, the requirements of the athlete must be considered within the context of their sport. For example, ski athletes perform their sport bilaterally and it may be logical to choose bilateral tests when quantifying asymmetries in strength and jumping tasks (38). However, team sports such as soccer and rugby hold a greater degree of unpredictability in an athlete's movement patterns; thus, unilateral testing or a combination of both may be most applicable. Additional reasons such as experience of the tester, ease of testing equipment and cost effectiveness should also be considered and will be discussed later in this review.

The aim of this review was to provide an overview of the current literature to critically examine which tests could be considered when quantifying asymmetries in strength and jumping-based tasks. Sub-headings of 'reliability', 'associations with athletic performance' and 'athlete requirements' have been provided to promote a clear rationale for suggestions made. Additional sections on how to interpret change (in asymmetry values) and practical considerations for testing will help to provide the reader with context on subsequent data analysis and expectations during test protocols. Finally, a test battery has been proposed for the assessment of asymmetries in strength and jumping-based tasks.

Methods

Empirical research studies and review journal articles were retrieved from electronic searches of Medline and SPORT Discus databases. The search strategy chose to combine specific terms with the word ‘asymmetries’ to ensure relevant articles were extracted. The search terms included: ‘asymmetries and strength’, ‘asymmetries and jumping’, ‘asymmetries and performance’, ‘reliability of strength tests’ and ‘reliability of jumping tests’. Articles were deemed relevant after scanning the title and abstract and where subsequent access to the full text was available from the relevant publishers. The reference lists of each study were also checked to ensure no further articles were omitted from the search process. All searches were conducted between the 1st November and 30th November, 2016.

Strength Tests

Reliability

The back squat has been used in a number of studies to examine the prevalence of force production asymmetries (22,31,47,58). Considering the bilateral nature of the exercise, any data pertaining to right and left differences would likely require the use of twin force plates. Strong reliability has been shown when testing bilateral 1RM loads for both novice and experienced lifters (ICC [intraclass correlation coefficient] = 0.94) (53) and healthy male (ICC = 0.99, CV = 0.35%) and female subjects (ICC = 0.97, CV = 0.53%) (60). Previously, a CV target of < 10% has been deemed acceptable (14); thus, it would appear that the 1RM back squat is a reliable method for testing strength across genders and experienced or inexperienced lifters. However, to the authors’ knowledge, only two studies have investigated data pertaining to vertical ground reaction force (vGRF) asymmetries during the back squat. Newton et al. (47) used 14 NCAA softball players to perform three back squats at 80% 1RM and reported average GRF asymmetries of 6.02%. Hodges et al. (31) examined vGRF asymmetry during the first and last two repetitions in each set of a training session that was comprised of 5 sets of 8 repetitions at 90% of their 8RM. Mean inter-limb differences (across all sets) were reported to be 4.3% for the first two repetitions and 3.6% for the final two repetitions. The results from these two studies indicate that vGRF asymmetries are low during the back squat for college and healthy adult populations; although further research is required to examine the reliability of inter-limb differences during this test.

The isometric squat or IMTP have also been used to measure asymmetry in the available research (4,5,6,19,25). Bilateral versions of these tests also require the use of twin force plates with peak vGRF most commonly reported (4,6,25). In addition, other variables that may be of interest to S&C coaches such as rate of force development (RFD) and impulse can also be calculated (19,25,40). Due to the restricted timeframe within sporting movements that athletes have to produce force (1), these physical characteristics can be considered an important diagnostic; however, the reliability of measurement may be questionable. Hart et al. (25) measured the reliability of peak force, mean force and RFD during bilateral and unilateral isometric squats. Results showed that rank-order repeatability via the ICC and within-subject variation via the CV for peak and mean force were acceptable based on previous guidelines (14). RFD was more variable (see Table 1), although it should be noted that this was on the non-dominant limb only. Furthermore, the subjects used in this study were not of a specific sporting background and as such may produce more variation in their results due to a possible lack of familiarity with testing protocols, which has been seen elsewhere (57).

**** INSERT TABLE 1 ABOUT HERE ****

For the IMTP, Dos Santos et al. (19) investigated the prevalence of strength asymmetries between professional rugby league and collegiate athletes. All subjects performed three bilateral and unilateral trials on each limb with peak force and impulse reported. Results showed strong reliability for unilateral peak force (ICC = 0.94; CV = 4.7-5.0%), but more variability for impulse (ICC = 0.82-088; CV = 9.3-11.6%). Significant differences ($p < 0.05$) between dominant and non-dominant limbs for both groups of athletes were reported, suggesting that the unilateral IMTP was a reliable method for determining strength asymmetries across athletes of different levels (19). In addition, reliability data has also been reported for both males ($n = 31$) and females ($n = 32$) during the IMTP. Bailey et al. (5) reported an ICC range of 0.68-0.98 for multiple variables including peak force, impulse at different time points, and RFD although individual ICC values were not specified for the tested metrics. The standard error of measurement (SEM), which is an indication of a score's accuracy (68), was also reported and the highest variability was noted for impulse at 50 m/s. Although individual ICC's were not reported, the SEM is a measure of absolute reliability and thus, is arguably a more important measure. With that in mind, lower levels of reliability for impulse are in agreement with the findings of Dos Santos et al. (19). Furthermore, the sample was divided into stronger and weaker sub-groups with SEM values significantly different ($p < 0.05$) between groups for peak force (0.07 vs. 0.13 s) and RFD (0.45 vs. 0.70 n/s^{-1}). The authors stated that strength may be a more influential factor than sex when calculating asymmetries during the IMTP due to the increased variability and inter-limb differences seen in the weaker group (5).

Isokinetic dynamometry is another alternative for practitioners who wish to measure both inter- and intra-limb strength asymmetries in isolated joint actions (such as knee flexion or extension). Research is available to analyse the presence of asymmetries in different populations ranging from collegiate (36,41,47) to professional athletes (15,55,59); however, none of these studies included data examining the reliability of inter-limb differences. Impellizzeri et al. (34) reported the reliability of isokinetic strength imbalance ratios (between hamstrings and quadriceps) showing weak to strong reliability (ICC range = 0.34-0.87). Furthermore, the SEM ranged from 3.2-8.7% for strength imbalance ratios and 4.3-7.7% for peak torque measurements. Similar reliability values have also been reported for intra-limb isokinetic knee flexion and extension measurements in recreational athletes (3). Concentric and eccentric actions were recorded at 60, 180 and 240°·sec^{-1} with reliability assessed via the SEM and ICC. All measures showed moderate reliability with the percentage error reaching as high as 20% and ICC's > 0.7 (3).

Effects on Athletic Performance

There is currently a paucity of literature to examine the relationship between asymmetry during the aforementioned strength tests and athletic performance. Bailey et al. (4) reported mean asymmetries during the IMTP of 6.6%, and moderate negative correlations between the peak force symmetry index and jump height (r = -0.39 to -0.52) and peak power (r = -0.28 to -0.43) across loaded (20 kg) and unloaded jumps. Furthermore, Rannama et al. (51) showed that peak torques asymmetries of the knee extensors (measured at 180°·sec^{-1}) were negatively correlated (r = -0.50; p < 0.05) with power during a 5-second maximal effort cycling test. Strength asymmetries have also been shown to have a detrimental effect on the performance of sport-specific actions. Hart et al. (26) used a unilateral isometric squat to determine inter-limb strength differences in Australian football players. Higher asymmetries (8%) were negatively associated with kicking accuracy compared to the accurate players who only exhibited 1% imbalances in strength. These data indicate that larger strength asymmetries may have a negative impact on performance; however, caution should be applied due to high amount of variance remaining unexplained by these relationships.

Athlete Requirements

When selecting appropriate tests to measure asymmetry, practitioners should consider their ecological validity. For example, bilateral assessments may be more suitable for a powerlifter, to ensure task specificity is being adhered to. Conversely, team sport athletes are required to undertake multiple unilateral sporting actions such as running and changing direction; therefore, it seems logical to suggest some form of unilateral strength testing when calculating asymmetries.

The type of muscle actions and speeds of movement involved in the sport are also a consideration in test selection. Isokinetic testing has the advantage of measuring asymmetries across a range of muscle actions (concentric and eccentric) and speeds unilaterally, potentially providing a more complete picture of strength asymmetries. However, strength during single joint actions is not fully representative of compound movement patterns (9,36), which are more characteristic of the actions required during the execution of the majority of sporting tasks. Furthermore, isokinetic dynamometry testing requires a laboratory and expensive equipment which may not be practically viable for many athletes or teams. Until recently, it could have been argued that this notion held true for the use of force plates; however, more recently affordable (and portable) versions are now available increasing their utility for field testing large numbers of athletes.

Jump Tests

Reliability

When determining asymmetries in jump tests, a variety of bilateral and unilateral tests have been frequently used (7,13,35,36,41,49,52,54,69), most likely because of their ease of implementation. Although inter-limb differences can be calculated with only one force plate, as per the methods of Impellizzeri et al (35), large movement variability in vertical jumping has been noted (8,38), perhaps suggesting that asymmetries should be determined within the same repetition if quantified bilaterally. Alternatively, asymmetries can also be measured via single leg jumping tasks through the use of a jump mat and assessment of flight time and ground contact duration. Whilst not a common topic, Benjanuvatra et al. (8) aimed to differentiate between the bilateral CMJ and SLCMJ for assessing asymmetries in impulse and vGRF. The authors suggested using the SLCMJ over the bilateral CMJ when quantifying asymmetries because it places a greater emphasis on force production from one limb and reduces the athlete's base of support presenting a challenge that is more representative of the actions performed for most sports. Furthermore, multiple sporting actions such as jumping and sprinting occur unilaterally; thus, the notion of specificity is kept to the sporting task if asymmetries are tested for unilaterally. Therefore, single leg tasks may provide a more accurate reflection of true inter-limb asymmetries for team sport athletes in particular. However, it should be noted that task specificity may ultimately dictate which jump test is chosen.

Meylan et al. (46) reported strong reliability for measures of jump height and distance during the SLCMJ and lateral jumps. ICC's ranged from 0.91-0.98 across both genders in healthy adults. Furthermore, CV ranges fell between 2.7-7.2%, suggesting that multi-directional, unilateral jumps are a reliable method for assessing between-limb differences. Strong reliability has also been noted in youth athletes for measures of peak force and power during the SLCMJ (13), with ICC's ranging from 0.88-0.97. Consequently, unilateral vertical jump assessments appear to be reliable tests across adult and youth populations.

The reliability of various single leg hop tests has also been measured within previous research (12,52,55). Common variations include the single leg hop (for distance), triple hop, 6m timed hop, and crossover hop (Figure 1). The single leg hop would appear to be the most reliable of these four tests with ICC's ranging from 0.92-0.96 and SEM's of 4.56-4.61cm, with more variability present in the 6m timed hop (ICC = 0.66-0.92) (12,52,55). Despite their similarities, it has been suggested that more than one hop test should be considered when quantifying asymmetries (48) because of the different demands they each pose. Considering the previously reported strong reliability of the triple hop test (ICC = 0.88-0.97), and notably lower SEM values when compared to the crossover hop (11.17 vs. 17.74 cm) (52,55), the rebound nature of the task may provide a more ecologically valid representation of unilateral tasks for athletes in running and jumping based sports. However, it must be acknowledged that this test likely places a greater physical demand on athletes and should be used with caution if plyometric training experience is low. Furthermore, it is plausible that a low training age for this physical quality may negatively affect the reliability of the test, rendering it unsuitable; although further research is again warranted to substantiate this theory.

**** INSERT FIGURE 1 ABOUT HERE ****

The reliability of various measures collected during drop jumping tasks has also been reported in the available research (2,17,21,67), although it would appear only recently that this exercise has been used to report asymmetries. Maloney et al. (44) showed bilateral drop jump asymmetries as high as 59.7% for leg stiffness, whilst within-session reliability (CV) was 5% for vGRF. However, CV's were noticeably higher for negative centre of mass displacement and vertical stiffness (12 and 13% respectively), although this may have been attributed to the sample not being an athletic population and therefore test familiarity must be questioned. Although not used for asymmetry detection, test-retest reliability (using the ICC) has previously been reported in the drop jump for measures of peak and mean force (0.86-0.98), jump height (0.99), and ground contact times (0.98) (17,21), indicating strong rank-order repeatability. However, further research is warranted to examine the reliability of these variables with respect to asymmetry.

While the majority of the available literature pertaining to the reliability of drop jumping tasks is focused on bilateral variations, the unilateral drop jump has also recently been examined (44). The authors reported similar levels of asymmetry as the bilateral test (~55%) and showed within-session CV's of 2% for vGRF, indicating small variability between trials in a non-athletic population. Stalbom et al. (62) investigated the reliability of impulse, mean and peak force during single leg drop jumping and found ICC's ranged from 0.74-0.96 and all CV's < 10%. Although both studies indicate acceptable levels of reliability, procedures were conducted from 18 and 20cm boxes respectively. Bilateral drop jump measures are frequently conducted from a height of 30cm (21,39,42), but the increased physical demand associated with a unilateral version would suggest that lower heights may be more appropriate. This is supported by Maloney et al. (44) who described how the required short ground contact times could not be maintained when dropping from heights of 30 and 45cm.

Effects on Athletic Performance

Lockie et al. (43) investigated asymmetries in different unilateral jump tasks and their relationships with performance tests. Between limb-differences of 10.4%, 3.3% and 5.1% were shown for CMJ height, broad jump and lateral jump distances respectively. No significant correlations were found between any of the asymmetry values and sprint (5, 10, 20m) or change of direction speed (CODS) tests (left and right 505 and modified t-test). These data indicate that asymmetries ≤ 10% do not negatively affect sprint of COD performance. This is supported by Hoffman et al. (32), with SLCMJ asymmetries of 9.7% showing no significant differences in time when performing the 3-cone drill to the dominant or non-dominant side. Significant weak correlations were reported for the SLCMJ non-dominant limb and the 3-cone drill for both dominant (r = -0.36; $p < .05$) and non-dominant (r = -0.37; $p < .05$) directions; yet no significance was found when compared with the dominant limb of the SLCMJ. This suggests that asymmetries may be task dependent and highlights the multi-faceted nature of CODS that requires multiple factors to determine its success (61).

In contrast, inter-limb differences measured during jump tests have been shown to detrimentally impact performance (28). Significant correlations were reported between unilateral jump test asymmetries (vertically, horizontally and laterally) and measures of mean (r = 0.40-0.43) and peak force (r = 0.38-0.48) during a reactive agility task. Furthermore, the dominant limb was significantly faster for agility push-off time (1.48 vs. 1.56 sec; $p < .001$) compared to the non-dominant side (28). Bell et al. (7) investigated how lean muscle mass asymmetries affected CMJ performance. Results portrayed that thigh and shank lean mass asymmetry accounted for 20% of the variance in force asymmetry. Further to this, lean mass asymmetry of the pelvis, thigh, and shank accounted for 25% of power asymmetries, both during the CMJ. Additionally, asymmetries in power > 10% during the CMJ resulted in decreased jump height of 9cm (effect size = *d* > 0.8), which represents a considerable reduction in jump performance. Maloney et al. (45) attempted to determine the relationship that asymmetries (during single leg drop jumps) had with a 90° cutting task (performed on a force plate). The sample was subsequently divided into slow and fast groups (n = 9 per group), with mean vertical stiffness and jump height asymmetry explaining 63% of the cutting task variance (r^2 = 0.63; p = .001). Furthermore, faster athletes portrayed significantly lower asymmetries for jump height (p = .026), perhaps indicating that minimizing differences in reactive strength could be advantageous to cutting performance also. These results support the notion that it may be advantageous to minimize inter-limb differences when aiming to optimize agility and jumping performance.

Finally, the majority of research pertaining to asymmetries in jump tests often report data relating to performance outcomes (such as jump height or distance) or propulsive forces. Intra-limb differences in eccentric forces or mechanics (such as landing in this instance) are seldom reported and should also be considered to build the asymmetry picture further. Pappas and Carpes, (50) showed that knee valgus was significantly greater when jumping forward (20cm) compared to a drop land (from a 40cm box), highlighting the notion of task-specificity for landing kinematics as well. Whilst minimal research pertaining to asymmetries during landing patterns currently exists, the relationship between eccentric forces and injury risk is recognised (15,36); thus, further research in this area for inter-limb differences is warranted.

Athlete Requirements

Similar to testing for asymmetries in strength, both the sporting needs analysis and individual athlete requirements should dictate which tests are chosen. However, the concept of movement variability must be considered during jump testing and will have considerable impact on how asymmetries are interpreted. Exell et al. (20) outlined how an asymmetry can only be considered "real" if the inter-limb differences are greater than the variability within an athlete's movement. This concept was originally investigated during running; however, Jordan et al. (38) noted a shift in how asymmetries presented themselves during both the eccentric and concentric phases of a CMJ, supporting this notion of movement variability in jumping. With that in mind, it is essential that coaches understand how to calculate movement variability. A well organised protocol will often assume three trials of a test (66), and the CV allows practitioners to quantify the variation between trials for said test (expressed as a percentage). With asymmetries also being reported as a percentage, this allows a comparison of asymmetry score compared to variability score, and ultimately will help to determine if an asymmetry is real. Therefore, for athletes that require multiple movement patterns in different planes of motion (29,30), it is suggested that practitioners consider initial testing both bilaterally and unilaterally. Subsequent data analysis such as the CV (which also serves as an indicator of variability) may provide an impression as to whether certain tests are deemed too unreliable for their athlete population, which will help to streamline future asymmetry testing. As outlined by Cormack et al. (14), practitioners should consider < 10% as a target threshold when determining the reliability of a test and this figure can then serve as a comparison to the subsequent asymmetry value.

Interpreting Asymmetry Scores

Determining critical thresholds for asymmetry that are linked to reductions in performance or heightened injury risk provides S&C coaches with useful data to design targeted training interventions for athletes. The available body of literature suggests that asymmetries are task-specific; meaning that practitioners should not expect to see the same inter-limb differences across different tests for the same physical quality. This is supported by Jones and Bampouras, (36) who reported that asymmetries varied across tasks with differences of 4.47% and 12.43% for jump and strength tests respectively. Furthermore, Schiltz et al. (59) reported strength and power asymmetries of 6.5 and 12% in professional basketball players during isokinetic and drop jump testing respectively; justifying undertaking tests across both physical competencies.

Where strength asymmetries are concerned, Bailey et al. (4) reported negative associations with jump performance when strength differences of 6.6% were seen from the IMTP. Hart et al. (26) noted significantly reduced performance in kicking accuracy with asymmetries of 8% measured using the unilateral isometric squat. However, with limited data relating specifically to asymmetries in strength and their effects on performance outcomes, a specific threshold cannot be substantiated at this time. For jump testing, asymmetries > 10% have been associated with a 9cm reduction in jump height (7); whereas, inter-limb differences ~10% in jump height (43) and power (32) have shown minimal effect on CODS performance. This provides further support for task-specificity pertaining to asymmetries, making it challenging to draw definitive conclusions regarding critical thresholds during jumping-based tasks as well. The relationship between asymmetry and injury has also been investigated and available data indicate inter-limb differences > 15% increases the risk of injury (24,38,48). Therefore, it could be suggested that a greater magnitude of asymmetry is required to place athletes at heightened risk.

A final point to consider when comparing different asymmetry scores across different studies is that multiple equations have been used to quantify inter-limb differences. Inconsistencies in the equations used can result in different asymmetry percentages even when the same score is attained by an athlete (10). For example, right vs. left jump height scores of 25 and 20cm can result in asymmetry values between 7.04-22.2% dependent on the equation used (10). A true comparison between studies would only exist if the same equation was utilized. Therefore, when measuring asymmetry, practitioners are encouraged to always use the same equation to ensure consistent and accurate longitudinal tracking of athletes. It is beyond the scope of this review to discuss the merits of each equation; however, the interested reader is encouraged to view the work of Bishop et al. (10) for further details.

Testing Battery

Based on the aforementioned evidence, a testing battery has been proposed for the assessment of asymmetries in strength and jumping-based tasks (Table 2). With strength being of undeniable importance in athletic performance (64), and jumping tasks occurring frequently in sporting actions (29,30), testing inter-limb differences for both competencies seems logical and may allow for a more complete picture of asymmetries. In addition, Table 3 provides an overview of instructions for each test so that practitioners can adhere to the methods that are likely to elicit the most reliable results. It should be noted that determining inter-limb asymmetries during sprinting and CODS tasks would also provide S&C coaches with useful information. However, the literature pertaining to asymmetries and these physical qualities is scarce and further research in these areas is required before any suggestions are made.

*** *INSERT TABLES 2 AND 3 ABOUT HERE* ***

Practical Considerations for Testing

Regardless of whether asymmetries are being calculated for strength or jumping tests, there are additional test considerations that practitioners should be aware of. Firstly, experience of the tester must be considered. It is common for certain tests to have specific requirements that aid in the standardisation of procedures. For example, it is often suggested that athletes should pull "as hard and as fast as possible" when performing the IMTP test (19); therefore, some level of experience or familiarity is required to know that this will likely elicit favourable results in variables such as RFD especially. Secondly, the ease of testing equipment must also be deliberated and it is likely that different considerations exist for strength and jump tests. For example, without twin force plates it is impossible to gauge information pertaining to vGRF asymmetries during strength testing. Whilst an alternative solution is to test for asymmetries using isokinetic dynamometry, this method is confined to a laboratory and may not be viable for many practitioners. Therefore, calculating asymmetries in strength will likely require force plates. For jump tests, many alternative options exist; however, force plates should still be considered a favourable option with multiple metrics available for both propulsive and landing forces. Alternatively, equipment such as Optojump and electronic jump mats will allow for asymmetries in metrics such as stiffness, ground contact time, and jump height to be determined. Therefore, if practitioners are unable to access force plates, viable alternatives do exist for jump testing in the field. Practitioners constrained by budgetary restrictions require simpler and more cost-effective methods whereby jump mats may be the default option. More recently, mobile technology in the form of the My Jump app has also been shown to be reliable for bilateral and unilateral jump testing (11). Therefore, whilst the gold standard is always preferable, measurement of asymmetries during jump tests should be considered by all practitioners regardless of budgets due to the wide range of options available.

Conclusion

The aforementioned evidence would indicate that there are advantages to choosing isometric squats or the IMTP (both bilateral and unilateral variations) when quantifying asymmetries in strength. Measuring peak force in particular would appear to be reliable across multiple populations; and the isometric squat has shown that higher asymmetries are associated with negative impacts on sport-specific tasks, and thus, performance. When combined with the fact that force plates are more easily accessible in the field due to the creation of more cost-effective versions, and dynamometry measures are primarily restricted to a laboratory setting, the IMTP or isometric squat are the favourable options when quantifying asymmetries in strength. When calculating asymmetries via jump testing, the concept of movement variability must not be forgotten. Initial jump testing may be best served both bilaterally and unilaterally for asymmetry detection. Once practitioners have determined the most reliable and appropriate test from the battery of jump tests, this will help to streamline future test protocols when determining inter-limb differences. Practitioners should keep in mind that asymmetries have been frequently shown to be task-dependent and although specific thresholds for reduced performance may not exist at present, asymmetries > 15% may increase an athlete's risk of injury. A final thought to this review is that by assessing asymmetries in both strength and jumping tasks, a more complete asymmetry picture is provided by quantifying differences for two commonly prescribed exercise types in S&C programming. This may allow practitioners to prioritize specific areas of their athletes' training programs and target reductions in asymmetry that are relevant to the athlete.

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Table 1: Intraclass correlation coefficients (ICC) and coefficient of variations (CV) for peak force, mean force, and RFD during bilateral and unilateral isometric squats (adapted from Hart et al. [25])

Variable		Bilateral ISO Squat	Unilateral ISO Squat (D)	Unilateral ISO Squat (ND)
Peak Force	ICC	0.97	0.96	0.98
	CV (%)	3.6	4.7	3.6
Mean Force	ICC	0.91	0.95	0.83
	CV (%)	8.4	6.1	9.3
RFD	ICC	0.94	0.93	0.36
	CV (%)	15.2	14.5	45.5
D = Dominant limb, ND = Non-dominant limb, RFD = Rate of force development				

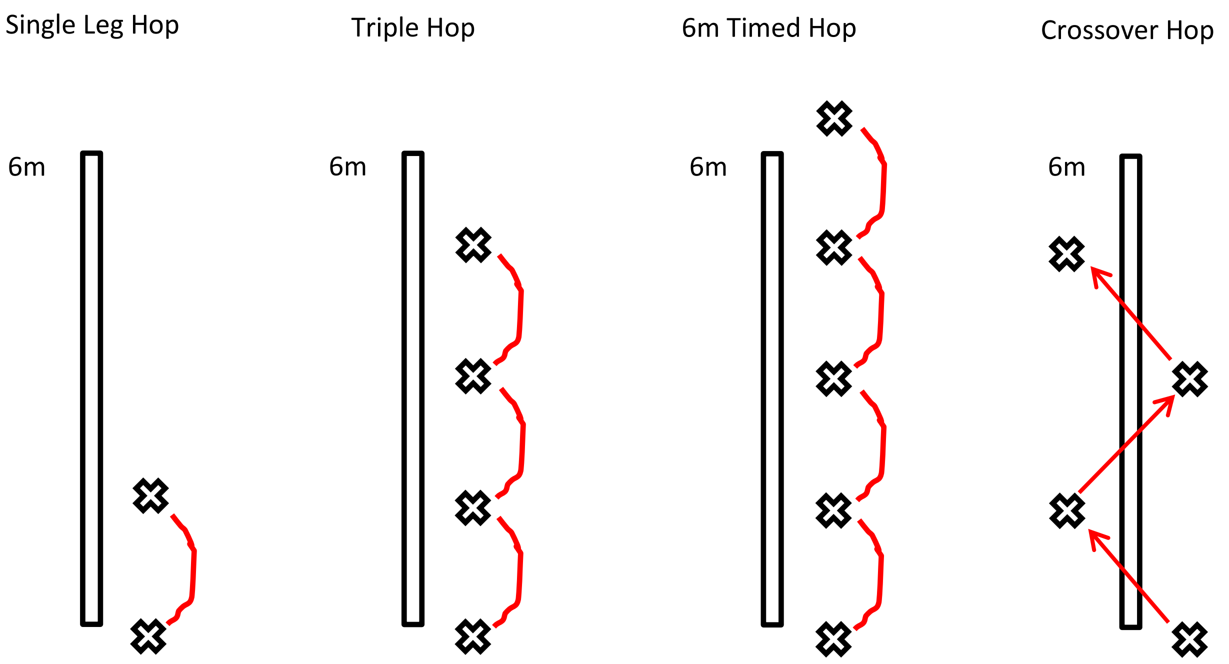

Figure 1: Diagrammatic representation of four commonly used hop tests to determine asymmetries. The single leg hop requires one maximal jump landing on the same limb. Failure to land without falling over or 'bouncing forward' requires the test to be retaken. The triple hop assesses maximal distance for three hops in a rebounding pattern. A stable landing must also be demonstrated for the final hop. The 6m timed hop positions timing gates at 0 and 6m and asks subjects to hop on one limb as fast as they can for the total distance; thus, reporting an outcome of time. The crossover hop requires three maximal hops (for distance) in a diagonal pattern. A stable landing must also be demonstrated on the final hop.

Table 2: Proposed testing battery for the assessment of asymmetries

	Metrics	Selected Test	Testing Equipment
Strength tests	Peak force, mean force, RFD, impulse	IMTP or isometric squat (+ SL variations)	Force plates
Jump tests	Peak force, impulse, jump height or distance	CMJ and BJ (+ SL variations)	Force plates (or jump mat), measuring tape
RFD = Rate of force development, IMTP = Isometric mid-thigh pull, SL = Single leg, CMJ = Countermovement jump, BJ = Broad jump			

Table 3: Instructions for how to administer different asymmetry tests

Test	Procedural Instructions
IMTP	Previous literature has outlined the knee angle to be set at 125° and the hip angle at 175° (4), with 180° representing full extension at both joints. Joint angles can be measured manually using a goniometer and weightlifting straps can be used to ensure a more secure grip on the bar. Once the position is assumed, athletes should be instructed to pull “as hard and as fast as possible” (16) which may aid in producing reliable results for variables such as RFD when measuring on force plates. For the unilateral version of this test, Dos Santos et al. (16) suggested that the non-stance limb be flexed 90° at the knee joint.
Isometric Squat	Hip and knee angles should be set at 140° with the bar resting on the upper trapezius muscle (as per standard high-bar back squat technique) (23,24). Athletes should be instructed to push “as hard and as fast as possible” which may aid in producing reliable results for variables such as RFD when measuring on force plates. For the unilateral version of this test, although not specified by Hart et al. (23,24), it seems logical to ask athletes to flex their non-working limb’s knee joint to 90°, as suggested for the IMTP procedures.
CMJ	Hands should be fixed onto hips so as to minimise any contribution from the upper body. Upon instruction, the athlete can dip to a self-selected depth during the countermovement prior to accelerating vertically as explosively as possible. Lower limbs should remain extended at all times during the flight phase of the jump before landing back on the force plate, jump mat, or ground. The same procedures should be followed for unilateral versions of this test.
BJ	Hands should be fixed onto hips so as to minimise any contribution from the upper body. Upon instruction, the athlete can dip to a self-selected depth during the countermovement prior to accelerating horizontally as explosively as possible, with the aim being to jump as far as possible (i.e.: a standing long jump). Trials are void and must be repeated if athletes are unable to stabilise on landing. When measuring distance, the reading should be taken (to the nearest millimetre) from the rear most heel closest to the start position. The same procedures should be followed for unilateral versions of this test.

IMTP = Isometric mid-thigh pull, RFD = Rate of force development,

CMJ = Countermovement jump, BJ = Broad jump